IEA Task 39 and Task 44 joint Task 44 "**Flexibility and biorefinieries**"

BORREGAARD – THE WORLDS MOST ADVANCED BIOREFINERY IN OPERATION – A PEEK INTO OUR SECRETS

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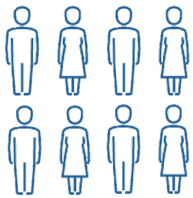
Technology Director Business Development
Borregaard AS

Borregaard
The Sustainable Biorefinery

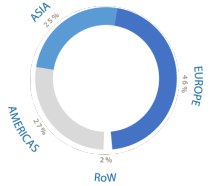
Borregaard key figures

Employees



1100

Borregaard in the world



Business in
16
countries

Sales to
110
countries

Sales outside Norway
95
percent

Economy

Turnover
5.0
billion NOK

Result
580
million

Investments
762
million

Raw material

1 million

m^3 Norwegian Spruce
500,000 tonnes lignin raw material

Production

Lignin
Speciality cellulose
Bioethanol
Vanillin
Cellulose fibrils
Fine chemicals

700
Products

Innovation

Innovation intensity
4-5%
of turn over

Sales of new products
12-20%
of turn over

Turning all parts of the wood log into products

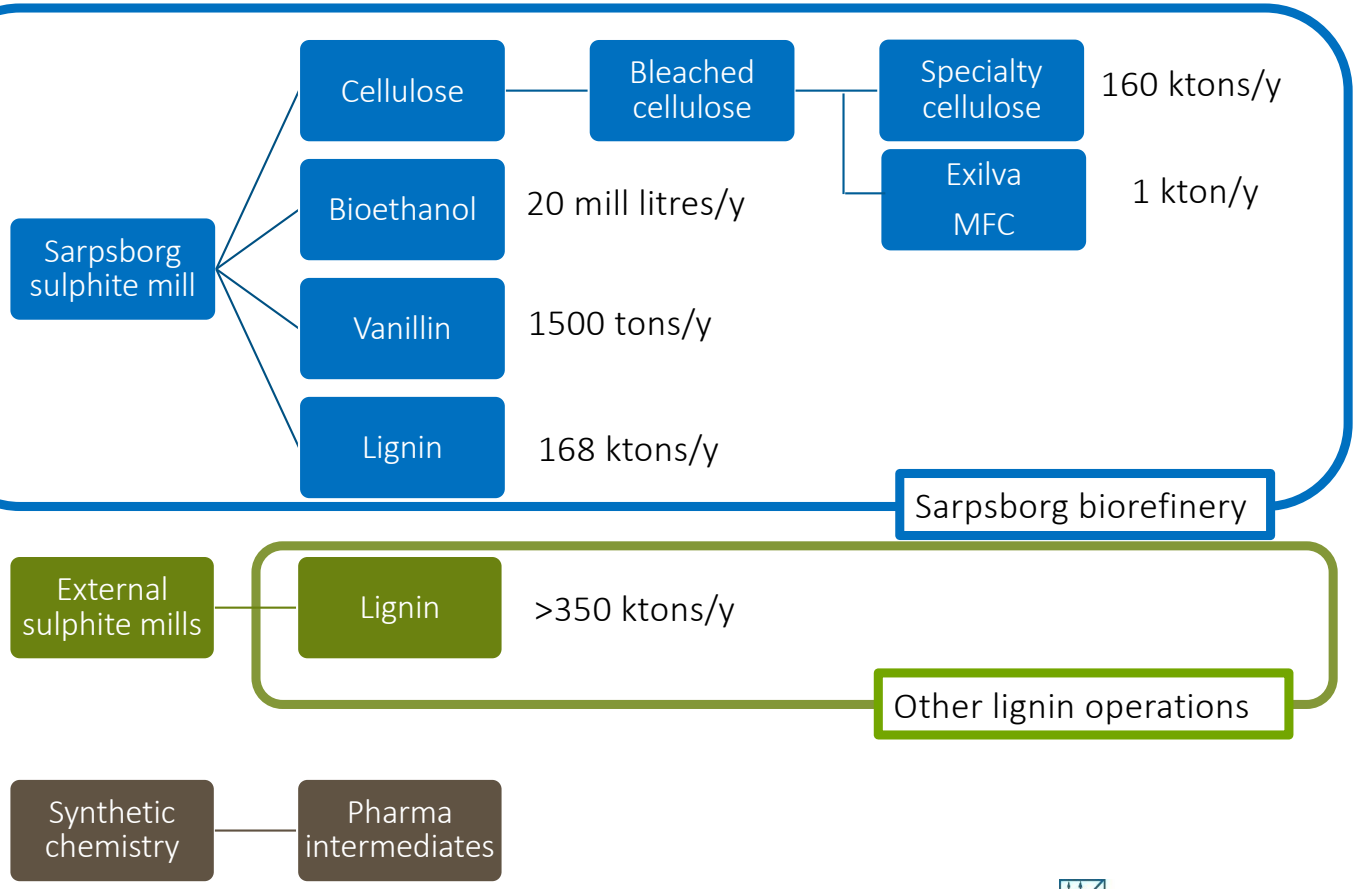
The "LIGNIN COMPANY"
Leading supplier of
lignin based
performance chemicals

Top 3 supplier of high
quality specialty cellulose

Only supplier of vanillin
from wood

Only supplier of MFC

The largest producer of
ethanol from wood



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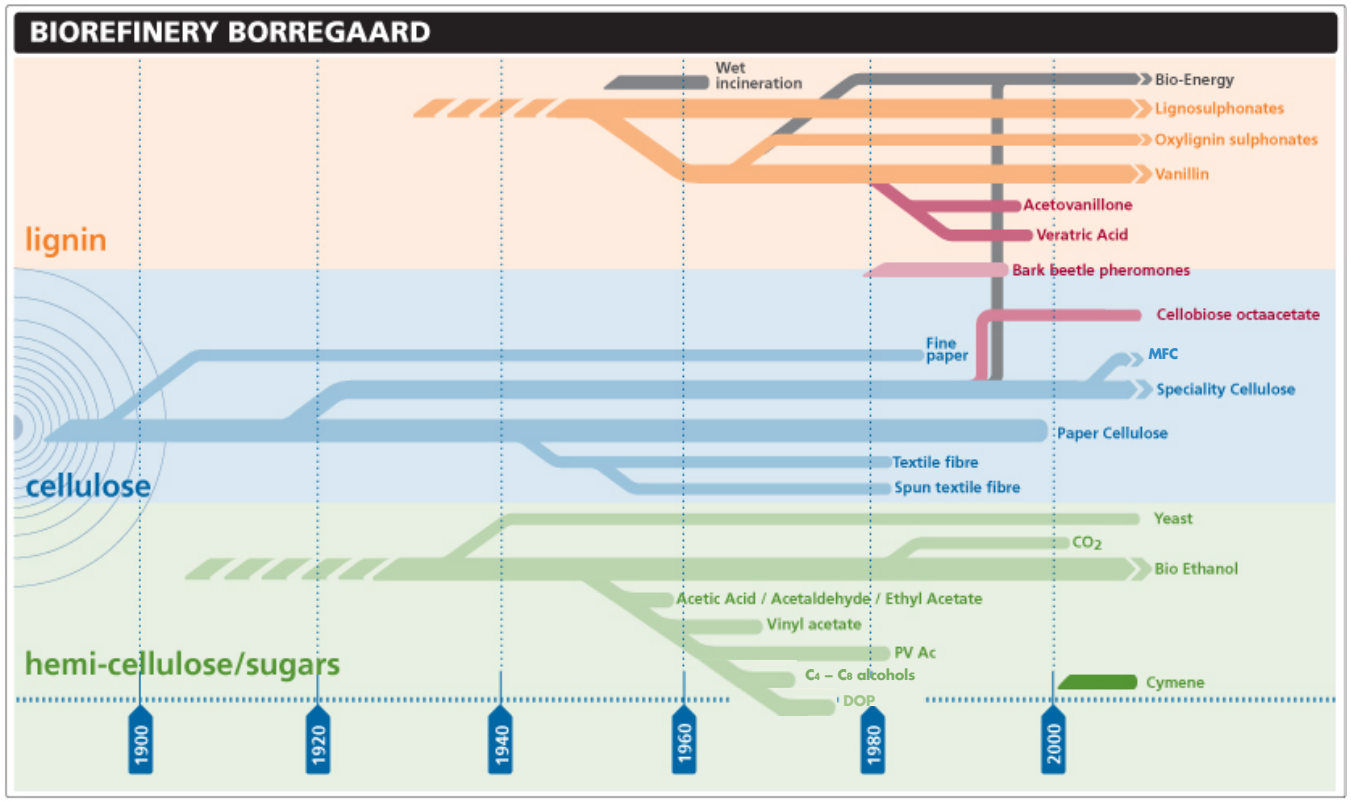
Learning points



Markets are never in balance

Expect lots of dynamics in markets, demands, competition, business conditions, feedstock suply, …..

Our survival depends on flexibility and flexible technologies

Avoid dependence on subsidies, tax reductions etc.

Avoid dependance on one single product

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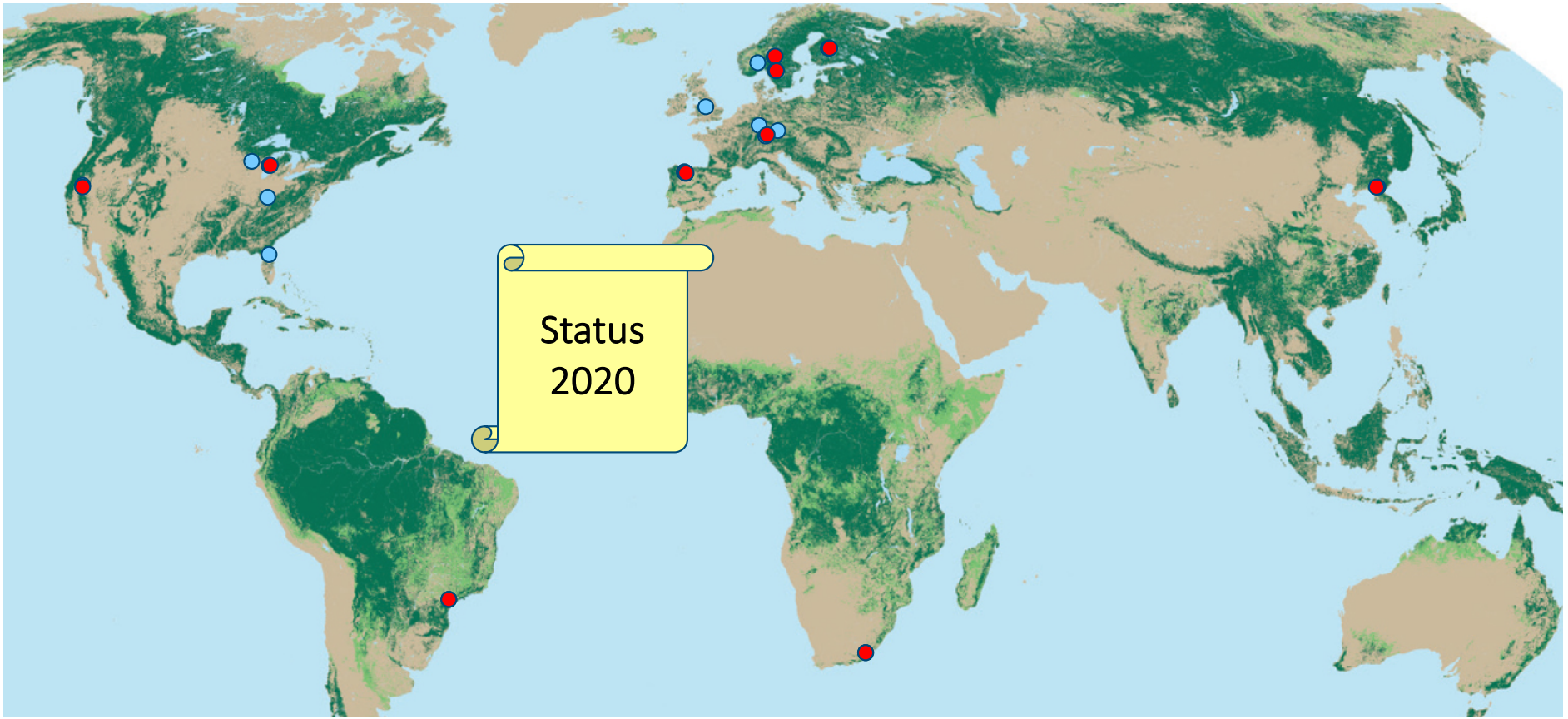
Borregaard globally



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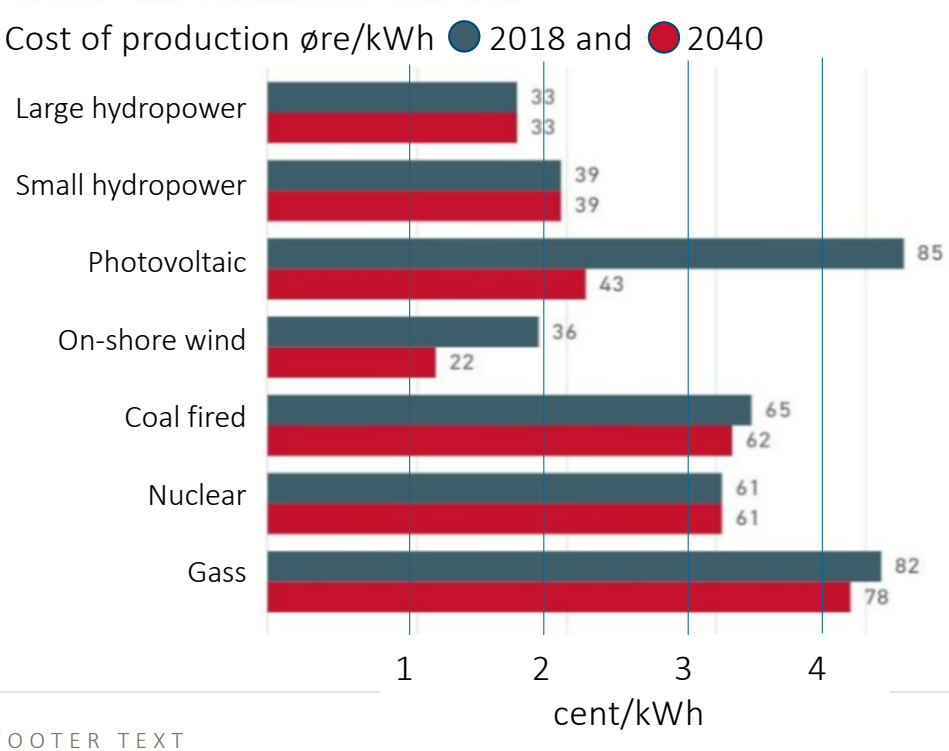
Energy supply in Norway 2020 and 2050

- 2020: 88% hydro power,
  7 % on-shore wind power
- Minor increase in hydropower to 2050



- Large potential in wind-power
  - Combination with hydropower magazins (fill inn)
  - Windy coast line

  => Lots of future low cost windpower
- Loss of income from oil and gas will be replaced by
  - more power intensive industry
  - aquaculture
- Electrification of industry and transport will need lots of power.
- Borregaard will need to replace steam production by municipal waste with electricity to reduce CO2 footprint

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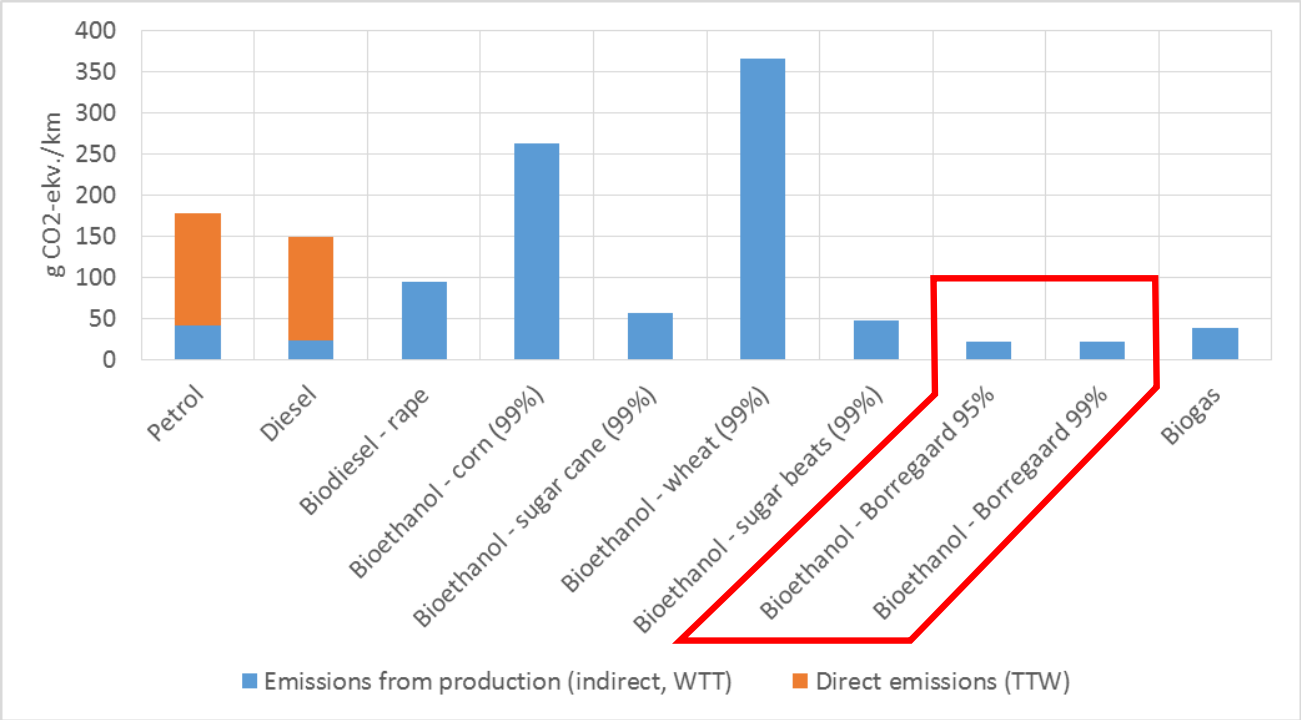
Integrated biorefinery – favourable LCA



- A recent LCA comparison of different fuels
- Integrated biorefinery is a winning concept

References:

Ecoinvent centre (2015) *Ecoinvent 3.1 LCA database*

Vincent, W et al. (2010) Clever - Clean Vehicle Research, Overview of vehicle technologies, Task 1.1

Yan, X. et al. (2013) Effects of Ethanol on Vehicle Energy Efficiency and Implications on Ethanol Life-Cycle Greenhouse Gas Analysis. *Environmental Science & Technology*

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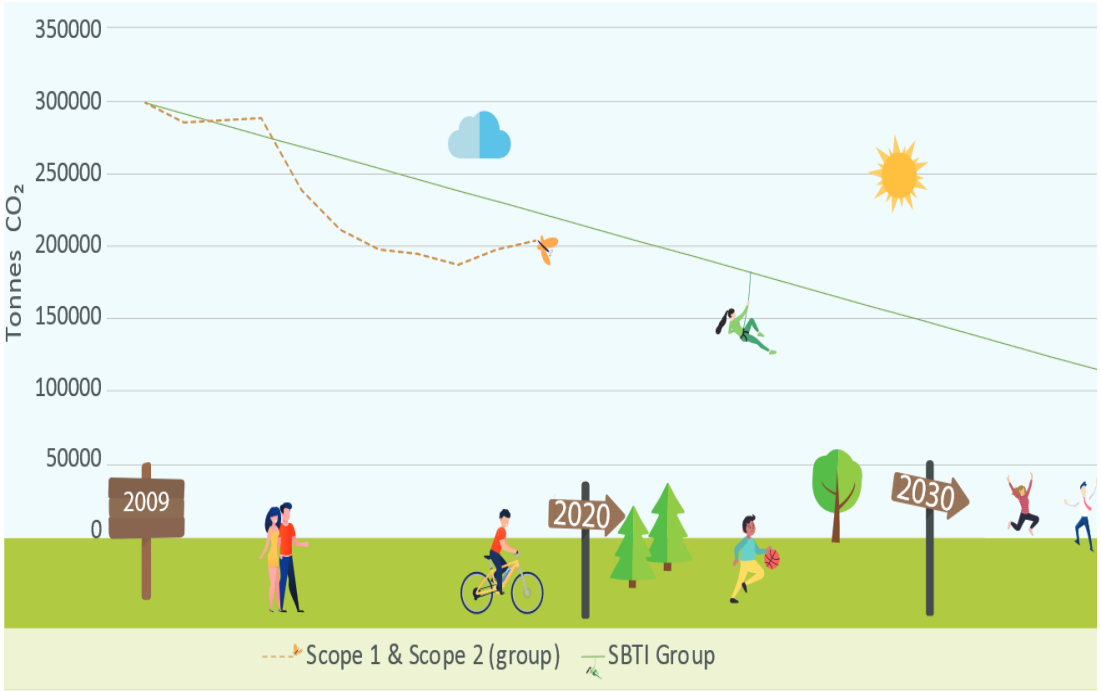
Borregaard towards zero emissions in 2050



Science Based Targets for GHG emissions approved by CDP

- Targeted reductions in greenhouse gas emissions:
  - 53% by 2030
  - 100% by 2050
  - Base year = 2009
- Targets are in line with the ambitions in the Paris Agreement and the Norwegian Climate law

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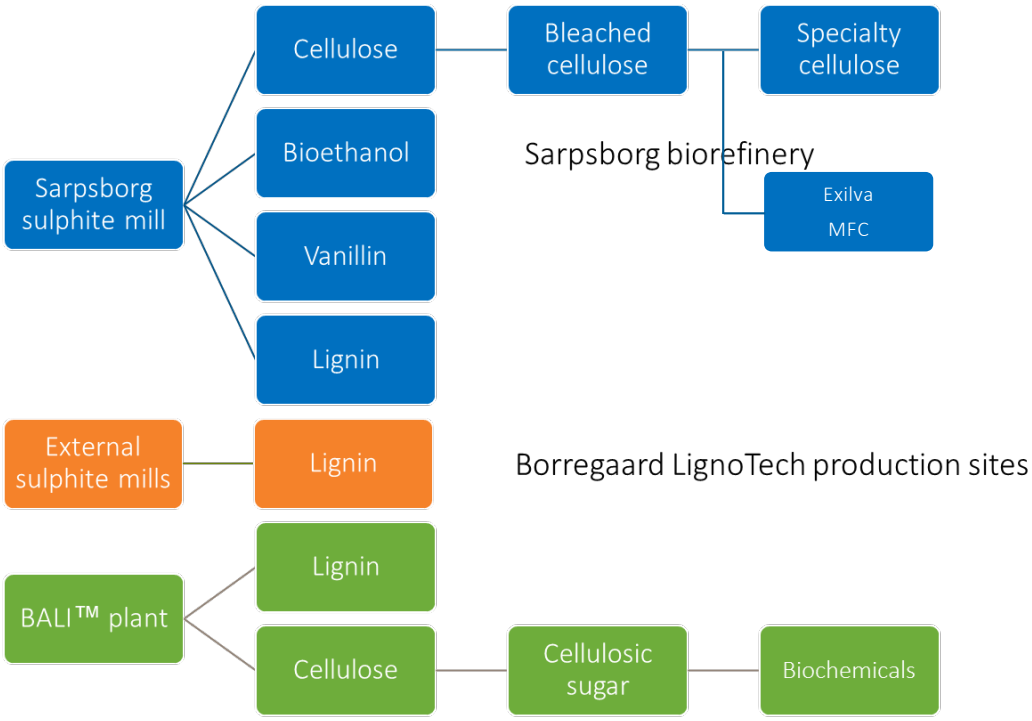
The BALI™ technology

- Expanding the lignin operation long term
- Co-production of lignosulfonates and sugars
- A demo plant has been in operation from
- Jan 2013
- Pretreatment
- Enzymatic hydrolysis
- Fermentation (GMO)
- 1-1.5 ton biomass dry matter pr day

- Technology ready for scale up when market is ready



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Excello range of cellulosic sugars

- Excello 90, 95 and 99 are the range of cellulose hydrolysates (glucose) from wood comming out of the BALI™ technology.
- Most fermentation processes can replace dextrose 95 directly with Excello 90.

Excello

	Excello 90	Excello 95	Excello 99
Typical use	Lignocellulosic drop-in replacement for starch based sugar		
Drop in for	DE95 syrup		Refined DE95 syrup
Total sugar (% of DM)	90%	95%	>99%
C6 of total sugar	90-95%		
Fermentation inhibitors	Insignificant		

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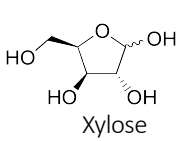
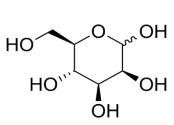
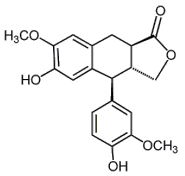
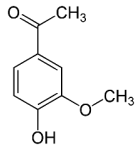
New possibilities in wood based biorefineries

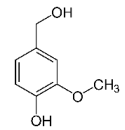
- Many additional streams can still be utilized and both specialty and large volume applications can be found
  - Lignins->aromatics
  - Specialty and rare sugars
  - Sugar platform chemicals
  - Extractives
- Biomass feedstock to oil refineries
  - Mass balance standards & voluntary schemes enable gradual replacement
  - Faster, lower risk and lower CAPEX than green field biorefineries

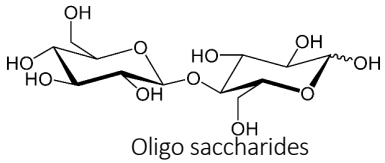

Xylose

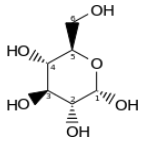

Mannose

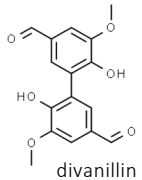

α-conidendrin

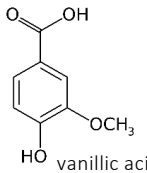

acetovanillone

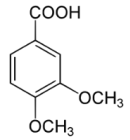

vanillyl alchol

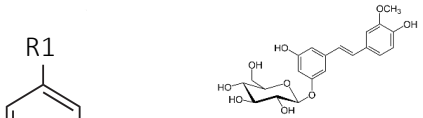

Oligo saccharides

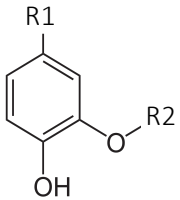

Glucose

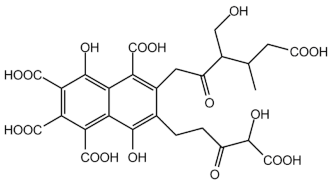

divanillin

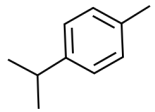

vanillic acid

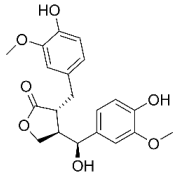

veratric acid

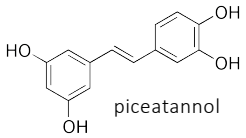

isorhapontin

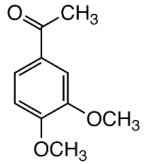

aromatics


Fulvic acid (example – many derivatives)


p-cymene (crude)


HMR


piceatannol


acetoveratrone

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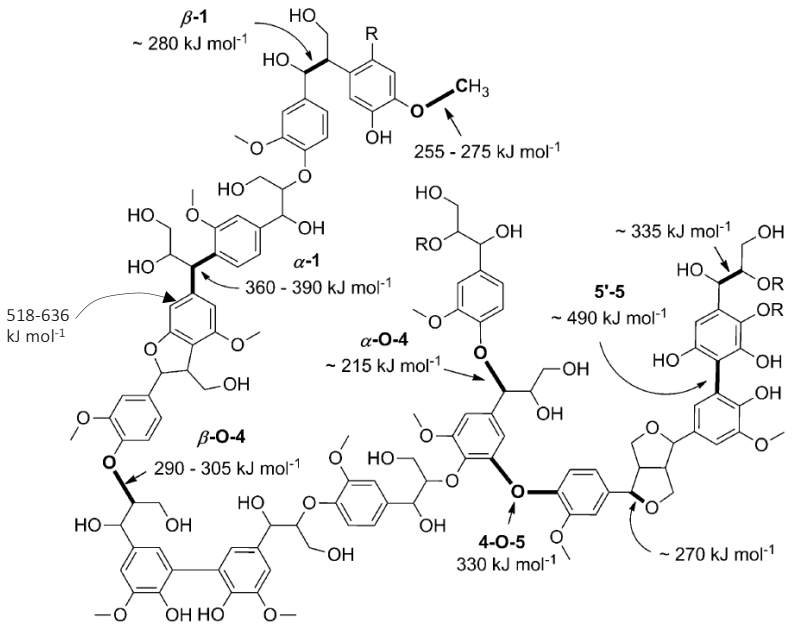
Lignins to aromatics

- No technological solution yet for breaking down lignin to aromatic monomers with acceptable yields and complexity of product



- Aromatic bonds are strong (518-636 kJ/mol)
- Aliphatic and ether bonds in lignin are weaker (255-390 kJ/mol)
- 5'-5 bonds are semi strong (490 kJ/mol)
- Thus, it should be possible to only break the aliphatic bonds without destroying the aromatic ring.
- Condensation and recombination is a major challenge

V. MOLINARI, C. GIORDANO, M. ANTONIETTI, D. ESPOSITO, *J. AM. CHEM. SOC.* **2014**, *5*, 1758.

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Thank you

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